NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

GUIDELINES FOR COMMAND, CONTROL, AND
COMMUNICATION COMPUTER NETWORKS
FOR THE REPUBLIC OF CHINA NAVY

by

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March 1990

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Postgraduate School; 6b OFFICE SYMBOL (If applicable) EC	7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000	7b ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000
8a NAME OF FUNDING/SPONSORING ORGANIZATION; 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO; PROJECT NO; TASK NO; WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification) GUIDELINES FOR COMMAND, CONTROL, AND COMMUNICATION COMPUTER NETWORKS FOR THE REPUBLIC OF CHINA NAVY

12 PERSONAL AUTHOR(S)
CHEN Chia-Hsin

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Master's Thesis	FROM ______ TO ______	1990 March	71

16 SUPPLEMENTARY NOTATION The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the US Governemnt.

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Command, Control, and Communications; Human Factors; Artificial Intelligence; Network Techniques; Network Communication Methodlogies; Local Area Networks (LANs)

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

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20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL LIND, Judith H.	22b TELEPHONE (Include Area Code) 408-646-2543; 22c OFFICE SYMBOL OR/Li

DD Form 1473, JUN 86 Previous editions are obsolete SECURITY CLASSIFICATION OF THIS PAGE

S/N 0102-LF-014-6603 UNCLASSIFIED

Approved for public release; distribution is unlimited

Guidelines for Command, Control, and Communication Computer Networks for the Republic of China Navy

by

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Submitted in partial fulfillment of the requiiements for the degree of

MASTER OF SCIENCE
IN TELECOMMUNICATION SYSTEMS MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
March 1990

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ABSTRACT

This thesis examines design criteria related to development of local and wide area networks for command, control, and communications (C3) systems, especially as such networks could be used by the Navy of the Republic of China, Taiwan. This study stresses the usefulness of modern computer networks and the importance of considering human factors and artificial intelligence systems during design of these networks. Various network technologies and communication methodologies used for local area networks (LANs) and wide area networks (WANs) are explored. Unified network systems for shore-based and ship-based systems and the integration of these systems are discussed. Information is included to provide Republic of China Navy officers with an awareness of how computer networks can improve C3 functions and make the military more efficient during both peacetime and wartime.

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I. INTRODUCTION

A. COMMUNICATION IN THE REPUBLIC OF CHINA NAVY

Command, control, and communications (C3) are critical for all military organizations, including the Navy of the Republic of China (ROC), Taiwan. Traditionally, telephone, radio, and mail have been used for C3 by the ROC Navy. Computers also are used by every ROC Navy base, unit, and some ships. However, currently the main function of computers used by the ROC Navy is data and file management. Information cannot presently be sent from one base to another using available computer systems.

ROC Naval officers report that communications between the ROC's Naval bases and ships are fragmented and suffer from lack of interoperability and interconnectivity. Outmoded manual procedures affect efficient communications and decision-making functions. Currently, each base and ship operates independently with respect to data communication and military administration. Human resources are used inefficiently and with much duplication of effort, because of the lack of coordination among shore bases and ships. The ROC Navy needs a new communications concept and a unified planning approach.

Students in ROC military academies are required to learn how to operate and understand computer systems, both software and hardware. They also must learn computer languages. In the ROC military, computer systems are used for research, development, design, and analysis. Computers are used for the operation of ships, submarines, aircraft, tanks, and ground systems. Maintenance, testing, and launching of many weapons and missile systems are carried out with the aid of computers. Yet, although civilians use networks to transmit messages from one location to another, the ROC military does not yet do this.

B. COMMAND, CONTROL, AND COMMUNICATIONS

In war, victory is the main object, and quick decisions are required for victory. Command, control, and communication are the terms used for processes which occur within and among structures erected to facilitate decision making. In establishing design criteria for ROC Navy C3 systems, command and control must be considered first.

"Command and control" is defined as the exercise of authority and direction by a properly designated commander of assigned forces in the accomplishment of the mission. Command and control functions are performed through proper use of personnel, equipment, communications, facilities, and procedures. These varied systems are employed by a military command in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission. [Ref. 1:p. 23]

Command and control for the ROC Navy concerns the movement and status of naval assets. These assets include ships, missiles, and other weapon systems. Command and control exists at all levels of the naval command echelon. Generally, the lower the level of command, the smaller the region and the number of assets that are of concern. Command represents the vested authority that a commander in the military service lawfully exercises over subordinates by virtue of rank or assignment [Ref. 2:pp. 8-9]. Control is typically associated with the commander's direction of forces.

Modern warfare, with high-technology weapon systems, requires real-time command and control for the exchange of data between the ship's various systems. Command and control must be combined with communications. The commander with the most capable C3 systems holds a decisive advantage. [Ref. 3:p. 35]

Command, control, and communication systems can be defined as unified systems of command and control links, nodes of maneuver forces, and weapons systems. Users of these systems are kept informed by a variety of sensors (e.g., radio, radar, and data link), which provide the information necessary for the planning and execution of coordinated combined arms operations.

In any battle theater, a commander must be able to command and control his forces so that his fighting assets are optimized. In a modern battle, movement of weapon systems is rapid, which means that reactions must be equally rapid. Such speed can only be obtained if commands are passed swiftly to the elements under the commander's control [Ref. 4:p. 1]. Traditionally, C3 systems have depended on radio communications for speed, long distance communications, and reliability. However, radio signals can be intercepted and jammed by enemy forces, and atmospheric conditions can interfere with transmissions.

C. COMMUNICATIONS USING NETWORKS

Communications can be defined as the transmission of information using various media (voice, data, and video). Although radio currently is the primary medium, a wide variety of communication media is available to the ROC Navy for communications. Computers and computer networks already play a central role in civilian communications, affecting the lives of most people.

Using computer networks, people can exchange, store, edit, broadcast, and copy almost any written document. Data and messages are sent instantaneously, easily, at low cost, and over long distances. Two or more people can look at a document and revise it together. They can consult with each other on critical matters without meeting or setting up a telephone conference, and can ask for and give assistance interactively. [Ref. 5:p. 1123]

The primary purpose of military communication is to facilitate the passing of commands from senior to junior officers, and to transfer information between individuals. Connecting command and control systems with communications systems to meet national C3 needs is one of the biggest problems faced in military communications today by the ROC Navy. The fundamental elements of effective communications are systems that are reliable, secure, fast, and flexible [Ref. 6:p. 1-1]. Computers provide a transmission medium that meets these fundamental requirements.

Communication using computer networks is widespread in modern countries. Networks are used in schools, in industry, and in the military. For example, the United States Defense Data Network (DDN) is a computer-mediated communication system that has been implemented in pre-existing military organizations. Using the DDN, information can be transmitted from any U.S. military base to any other, even to overseas bases through the use of satellites. The DDN is a very effective network, used extensively for military purposes.

D. COMMUNICATION NETWORKS FOR THE ROC NAVY

Computers have become important tools for modern war in the air, at sea, and under water. Computer networks can be even more useful than individual computers, when they are used efficiently by the commander. For effective use, the commander must understand the basic problem-solving logic used by computers to correlate information in his command centers. He also must know how to send and receive messages via computer networks. Internetworking technology can improve C3 functioning during modern war, resulting in rapid, broad, and timely authority for the conduct of battles.

In order to implement computer networks in the most efficient manner, it is necessary that the ROC Navy recognize and understand the technology related to these networks. It is critical to define the C3 functions that computer networks can perform for the ROC Navy, and the advantages that can be expected from such networks. The kinds of communication network technologies that could be used by the ROC Navy must be determined, along with the impact on humans that may be expected from network communications.

One reason for not using computer networks for military communications is the potential danger of compromising critical information. Security must be paramount in all military applications of computers, especially personal computers (PCs). Much military information is potentially damaging to national security, if obtained by enemy countries. It is absolutely essential that military organizations determine the measures that are required to ensure security before procuring or installing PCs and before initiating computer networks. [Ref. 7:p. 148]

Several other factors must be studied prior to deciding whether a computer communication network will be cost effective for the ROC Navy. Design criteria must be specified both for local area networks and for wide area networks. Techniques must be located for developing an operational computer network that can link shore bases and ships for fast and secure transmission of C3 information. Possible use of artificial intelligence systems should be explored, and the effect of human factors on C3 must be examined.

E. THESIS GOAL AND OBJECTIVES

1. Goal

The overall goal of this thesis is to investigate requirements and to establish design criteria for C3 systems that may be applied to potential computer networks for the ROC Navy. The purpose of this research is to improve C3 via the use of timely, rapid, survivable, and secure data processing and communications, using computer networks. This study emphasizes that, by using computer networks, the capabilities and efficiency of C3 systems in the ROC Navy can be increased.

2. Objectives

This study stresses naval mission requirements and new network technologies in order to provide information needed for naval C3 systems. Since modern C3 technology requires a synergistic relationship among computer science and information science, these topics also are discussed. The specific objectives of this thesis are as follows.

a. Command, control, and communications functions are defined, the advantages of computer networks for these C3 functions are discussed, and the kinds of information needed for effective network implementation are noted.

b. Requirements for satisfactory networks are discussed, and the roles of humans and of artificial intelligence systems are explored.

c. The three basic kinds of system architecture currently used for networks are described, along with their associated communication techniques and relative advantages and disadvantages.

d. Network communication technologies for local area networks are described, including transmission media, topologies, and access control techniques; signal transmission techniques for wide area networks also are described.

e. A unified communications network for the ROC Navy is explored, in order to link shore bases and ships for C3 functions.

f. Recommendations are made concerning the computer network technologies that may provide the optimum C3 systems for the ROC Navy.

II. DEVELOPING SATISFACTORY NETWORKS

A. REQUIREMENTS FOR A SATISFACTORY NETWORK

Networking is a form of communication; that is, it is people talking to people [Ref. 8:p. 8]. Today's networks provide the ability to control many distributed systems. They can make communication easier and more timely. Communication via telephones and computer networks now affects lives everywhere. Telephone networks are used for interpersonal communications, and for communication between organizations, to share information. Computer networks are groups of computers joined by data-carrying links. Computer networks often use telephone lines to carry data from one computer to another.

Using computer networks, people can exchange, store, edit, broadcast, and copy written documents. They can send data and messages instantaneously, easily, at low cost, and over long distances. Two or more people can look at a document and revise it together. They can consult with each other on critical matters without meeting together or setting up a telephone conference. They can ask for and give assistance interactively. [Ref. 5:p. 1123]

The most elegant and carefully thought out network will be unacceptable if it is too expensive or unreliable. Thus, requirements for planned networks must be completely identified before these systems are developed. This is especially true for a network which will be used for military purposes. [Ref. 9:p.38]

1. Cost

The cost of connecting to a network must be modest compared with the cost of the attached devices, that is, the computers and peripheral equipment. The network itself serves only as a connection device, enabling access to resources that often are quite expensive. Experience indicates that 10-20 percent of the cost of the attached computers will generally be acceptable for the cost of attaching to the network system. [Ref. 9:p. 39]

2. Reliability

Future military offices and installation will be as dependent on computer data communications as present-day commands are on their telephones. Very high reliability is therefore essential. This means both that system faults should be very rare and that users have confidence that problems will be fixed quickly.

3. Ease of Installation

Networks should be easy to install, modify, and extend. It will often be necessary for non-technical staff to move machines and to attach new ones, so these operations, at least, must not require technical skills. Moving one system should also have the least possible effect on other users.

4. Error Protection

Networks should have very low transmission error rates and should detect a large majority of the errors that do occur. If the inherent reliability is sufficiently high, the network itself need not correct detected errors; decisions about errors may be left to the attached devices.

5. Connectivity

Each computer attached to a network should be able to interact directly with other attached computers. In addition, it should be able to communicate with all the attached terminals.

6. Delays

If the network is to provide for interactive speech or real-time communication between users, it should offer a constant and low-delay service, and the maximum possible delay should be known. If the network is used for process control applications, it should provide a constant and low-delay service for transmission of small packets of data.

7. Interworking

Devices attached to a local network should be able to access various wide-area networks. These networks include public telephone networks and public packet-switched and circuit-switched networks. Teletex and videotex networks also should be accessible, along with those of commercial service time-sharing systems. [Ref. 9:pp. 38-41]

B. HUMAN ROLES IN NETWORKS

Numerous civilian and military people already use computers for communicating and decision making. Adequate human performance while using computers definitely is an important factor in developing a satisfactory network. Experience with the human users of existing networks indicates that if the systems are well designed with the user in mind, performance will be enhanced by the availability of network communications.

Human factors is an engineering discipline that discovers and applies information about human behavior, abilities, limitations, and other characteristics to the design of tools, machines, systems, tasks, jobs, and environments for productive, safe, comfortable, and effective human use [Ref. 10:p. 5]. Currently much human factors effort is being spent on the design of human-computer interfaces, that is, the displays shown on computer monitors and the keyboards and other devices used for data entry and issuing computer commands.

For optimum human performance, it is critical that human factors principles and guidelines be applied throughout development of a computer-based network system used for C3 functions [Ref. 11:p. 40]. Applications begin during feasibility studies for the network. At this time, the following human factors tasks should be carried out.

1. Formulate the appropriate human factors design requirements and ensure that these are integrated into the emerging solution.

2. Decide upon those system functions that will be automated and those that will be manual.

3. Establish the availability of manpower to use, operate, maintain, and manage the system.

4. Seek out and describe the organizational and operational implications of the system solution as so far conceived and establish whether these are acceptable. [Ref. 11:p. 41]

During system development, human factors engineers are concerned with the actual design of system components with which the users must interact. Specifically, workstations, display formats, and input/output devices must be optimum for the jobs to be done. The tasks the users will perform must be designed, and human-computer dialogues developed [Ref. 11:p. 42].

Computer-based C3 systems must be compatible with the requirements of military commanders in order to ensure that their decisions are effective. Task analysis is a human factors methodology that determines user requirements for task completion in complex systems. This is one of several techniques that may be used to ensure that networks and C3 systems are designed for rapid, accurate use by military personal. [Ref. 12:p. 61]

How well C3 functions are carried out is determined by the human-computer interface. Psychological data and human capabilities must be considered, especially when using high technology equipment. [Ref. 12:p. 62]

C. ARTIFICIAL INTELLIGENCE SYSTEMS FOR C3 AND NETWORKS

Artificial intelligence (AI) is commonly defined as the effort to develop computer-based systems (both hardware and software) that behave as humans behave [Ref. 4:p. 531]. This discipline brings to bear not only enormous computational capability, but machine powers of abstract analysis, vision, hearing, and touch. It affords the possibility of machines representing, learning about, and accommodating to a world of people, objects, and events. [Ref. 13:p. 203]

The future C3 environment is a domain where decision making will be increasingly *complex*. At war, the commander constantly is faced with difficult decision-making tasks, uncertain information, and vast quantities of data from modern sensors and communications systems.

Computers already can deal with broad and difficult classes of military problems. The technology associated with encapsulating knowledge and other AI techniques can significantly affect future military computer systems. Expert systems and other knowledge-based systems may be employed to assist commanders in coping with the massive information processing, analysis, and decision-making requirements.

Any new C3 system or network must consider AI programs as adjuncts to conventional' software, during design and development. Such capabilities may result in significantly improved human computer interfaces and significantly better military decisions.

III. BASIC NETWORK TECHNIQUES

The aim of network communication is to exchange data messages between a source station and its destination. This transfer can be one way or two way [Ref. 14:p. 15]. A communication network is a resource to be shared between two or many stations. The network provides for the sharing of transmission facilities among many stations, which reduces the cost incurred by any pair of stations. Since the purpose of a communication network is simply to transfer data from one place to another, the network is not concerned with the content of the data. The format of the data is important, however.

Communication networks be categorized based on the architecture and techniques used to transfer data. Three types of networks are in common use and will be discussed here. [Ref. 15:p. 195]

A. SWITCHED COMMUNICATIONS NETWORKS

A switched communication network consists of an interconnected collection of nodes. Data are transmitted from source to destination by being routed through the network of nodes. Figure 1 on page 17 is a generic illustration of the concept [Ref. 15:p. 195]. The nodes are connected by

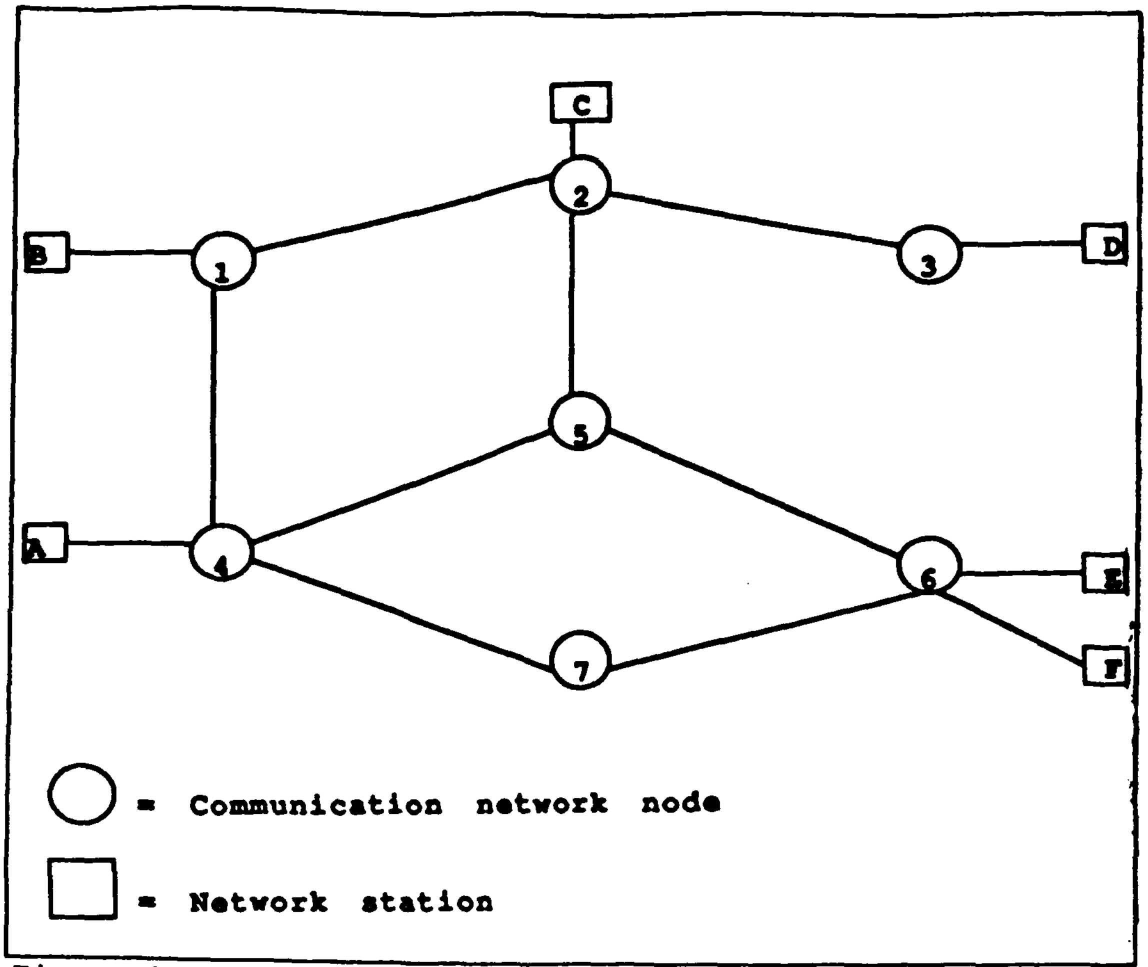

Figure 1. Generic Switching Network [Ref. 15:p. 195]

transmission paths. Data entering the network from one station are routed from node to node to a destination station. At each node the data are switched to the next transmission path along the way. Switched networks are classified as circuit, message, or packet networks. These terms refer to the way in which the nodes switch data from one link to another on the way from source to destination. [Ref. 15:pp. 195-196]

1. Circuit Switching

Circuit switching transmissions go through three phases.

* Circuit establishment: An end-to-end circuit is established via the switching nodes; one circuit may be multiplexed with others.

* Data transfer: The circuit is dedicated to a given transmission for the duration of data transfer.

* Circuit disconnect: The circuit is released at the request of either the sending or receiving station.

Circuit switching has little end-to-end delay once the circuit is established. It supports both real-time and interactive traffic. However, it is inefficient for burst traffic because the circuit is idle most of the time. Circuit switching transmissions are most efficient for transfer of bulk data.

2. *Message Switching*

Using message switching, a message is delivered from node to node in a "store and forward" fashion. At each node, the entire message is received, stored briefly via some means of computer storage, and then is forwarded to the next node. There is no limit on the message size. A message is delayed at each node for the time required to receive all bits of the messages. There is also a queuing delay before it is retransmitted to the next node. Message switching is inappropriate for real-time or interactive traffic because data delay is relatively long and highly variable.

3. Packet Switching

Packet switched transmissions use store-and-forward delivery much like message switching. However, packet switching places a tight upper limit on the size of each data unit. Their small and relatively constant size permits such data units (called packets) to be buffered in a computer's main memory at each node instead of requiring external storage. Limiting data packet size has a dramatic effect on performance. The transmission of each packet takes only milliseconds. Also, the first packet of a multipacket message can be forwarded before its second packet arrives at a node, thus reducing delays. Packet switched transmissions are well suited for real-time and interactive traffic. Transmission lines are utilized efficiently, since they can be shared by packets from unrelated sources as the packets travel to unrelated destinations.

Two approaches are used for packet switching of data. These are referred to as datagram and virtual circuit switching.

With virtual packet switching, a logical connection is established first, then all packets for a given message are sent through the logical circuit. Each packet is labeled with a virtual circuit number and a sequence number. Packets are delivered to the destination node in the same order as they are sent by the source node.

For datagram switching, each packet is treated independently just as each message is treated independently in message switching. The individual packets are labeled with a destination address for the receiving station and with an indication of packet assembly order. Packets may arrive in any order at the destination node because they may be forwarded on different routes. The packets then are reassembled in proper order after all have been received.

4. Comparison of Switched Communication Network Techniques

Figure 2 on page 21 shows event timing for the four communication network techniques discussed above [Ref. 15:p. 204]. For circuit switching (Figure 2(a)), a certain amount of time must elapse before the message can be sent. First, a call request signal is sent through the network to set up a connection to the destination. If the destination station is not busy, a call-accepted signal returns. Note that a processing delay is incurred at each node during the call request. This time is spent at each node setting up the connection to the next node. On the return, this processing time is not needed since the connection is already set up. After the connection is established, the message is sent as a single block, with no noticeable delay at the switching nodes. Circuit switching is an essentially transparent process, providing a constant data rate across the network.

Message switching (Figure 2(b)) does not require that a connection be established from source to destination before

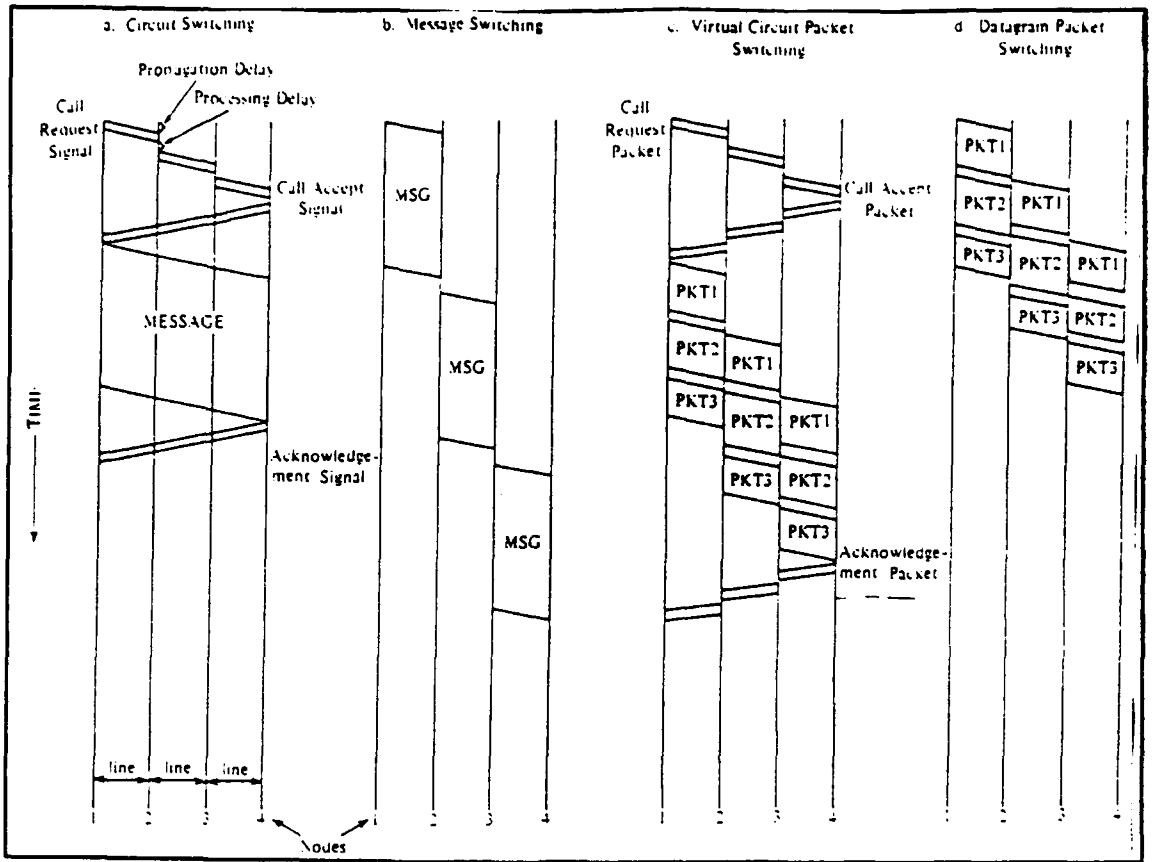

Figure 2. Event Timing for Various Communication Switching Techniques [Ref. 15:p. 204]

transmission begins. However, the entire message must be received at each node before that node begins to retransmit. Thus the total delay using message switching is almost always significantly longer than for circuit switching.

Virtual circuit packet switching (Figure 2(c)) appears quite similar to circuit switching. A virtual circuit is requested using a call-request packet, which incurs a delay at each node. The virtual circuit is accepted with a call-accept packet. Once the virtual circuit is established, the message is transmitted in packets. In contrast to the circuit-switching case, the call-acceptance signal also experiences node delay, even though the virtual circuit route is now established. The reason is that each packet is queued at each node and must wait its turn before transmission. This delay is variable and will increase with increased load. [Ref. 15:p. 205]

Datagram packet switching (Figure 2(d)), like message switching, does not require connection set up. Each node along the route may begin transmission of each packet as soon as that packet arrives. It need not wait for the entire message. Thus, datagram packet switching is almost always significantly faster than message switching.

Table I on page 23 compares several parameters related to circuit-switched, message-switched, datagram, and virtual circuit networks. In general, packet-switched networks are the most cost effective. Modern computer networks are usually packet switched. Circuit switching is used occasionally, but message switching is rarely used.

B. BROADCAST COMMUNICATION NETWORKS

Communication networks that broadcast their transmissions do not use intermediate switching nodes. Each station has at least one transmitter and receiver for sending and receiving communications signals over a medium shared by other stations. Signals usually are sent through the air. Broadcast networks have the following characteristics.

TABLE I. COMPARISON OF CIRCUIT-SWITCHED, MESSAGE-SWITCHED, DATAGRAM, AND VIRTUAL CIRCUIT COMMUNICATIONS NETWORKS [Ref. 15:p. 207]

CIRCUIT SWITCHING	MESSAGE SWITCHING	VIRTUAL CIRCUIT PACKET SWITCHING	DATAGRAM PACKET SWITCHING
Dedicated transmission path	No dedicated path	No dedicated path	No dedicated path
Continuous transmission of data	Transmission of messages	Transmission of packets	Transmission of packets
Fast enough for interactive	Too slow for interactive	Fast enough for interactive	Fast enough for interactive
Messages are not stored	Messages are filed for later retrieval	Packets may be stored until delivered	Packets may be stored until delivered
The path is established for entire conversation	Route established for each message	Route established for entire conversation	Route established for each packet
Call setup delay Negligible transmission delay	Message transmission delay	Call setup delay Packet transmission delay	Packet transmission delay

* No switching devices are included in basic system architecture.

* Data transmitted by one station is received by many, and often all, of the other stations on the network.

* Since stations share a common transmission medium, some form of access control is required to prevent signal overlapping. [Ref. 15:p. 207]

Packet radio and satellite networks are two types of broadcast networks that are in common use. In both cases, stations on the same networks transmit and receive signals via antennas, and all stations on that network share the same channels or radio frequencies. [Ref. 15:pp.207-208]

1. Terrestrial Packet Radio Networks

All stations that are part of a single packet radio network are within transmission range of each other. Transmissions are limited to line-of-sight paths; that is, ranges are limited to between 80 and 110 km. Each station can broadcast directly to all other stations on the network (see Figure 3.

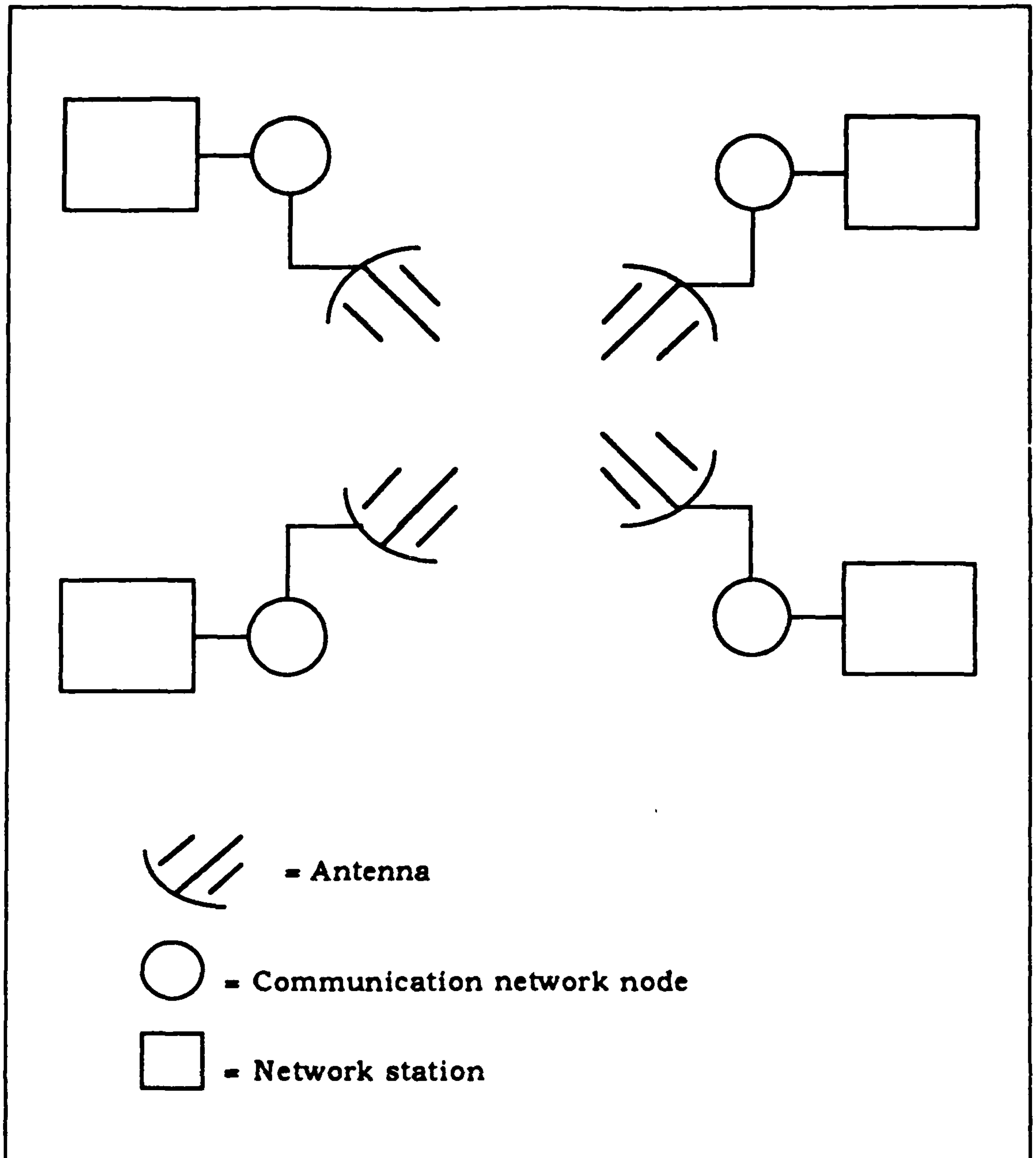

Figure 3. Terrestrial Packet Radio Architecture [Ref. 15:p. 196]

As is shown in Figure 4 on page 26, packet radio network architecture can be classified as centralized or distributed [Ref. 15:p. 286]. A centralized network (Figure 4(a)) has one central transmitter and receiver, attached to equipment resources shared by all nodes. All other nodes communicate only with the central node. That is, node-to-node communication is indirect, mediated by the central node. The earliest networks followed this model, and were designed primarily to provide terminal access to a central time-sharing system.

A centralized system requires two radio channels. Individual nodes send packets of data to the central node on one channel, and the central node broadcasts packets back to the nodes on another. Since radio transmission is omnidirectional, packets transmitted by the central node are heard by all the other nodes. Centralized networks are not appropriate for transmission of data, messages, programs, etc., between nodes consisting of microcomputers.

A distributed network takes full advantage of the omnidirectional property of radio (Figure 4(b)). A single channel can be used for all transmissions. Each transmission from every node is heard by all other nodes on the network. [Ref. 15:pp. 286-288]

2. Satellite Networks

In a satellite network, data are not transferred directly from ground transmitters to receivers but are instead

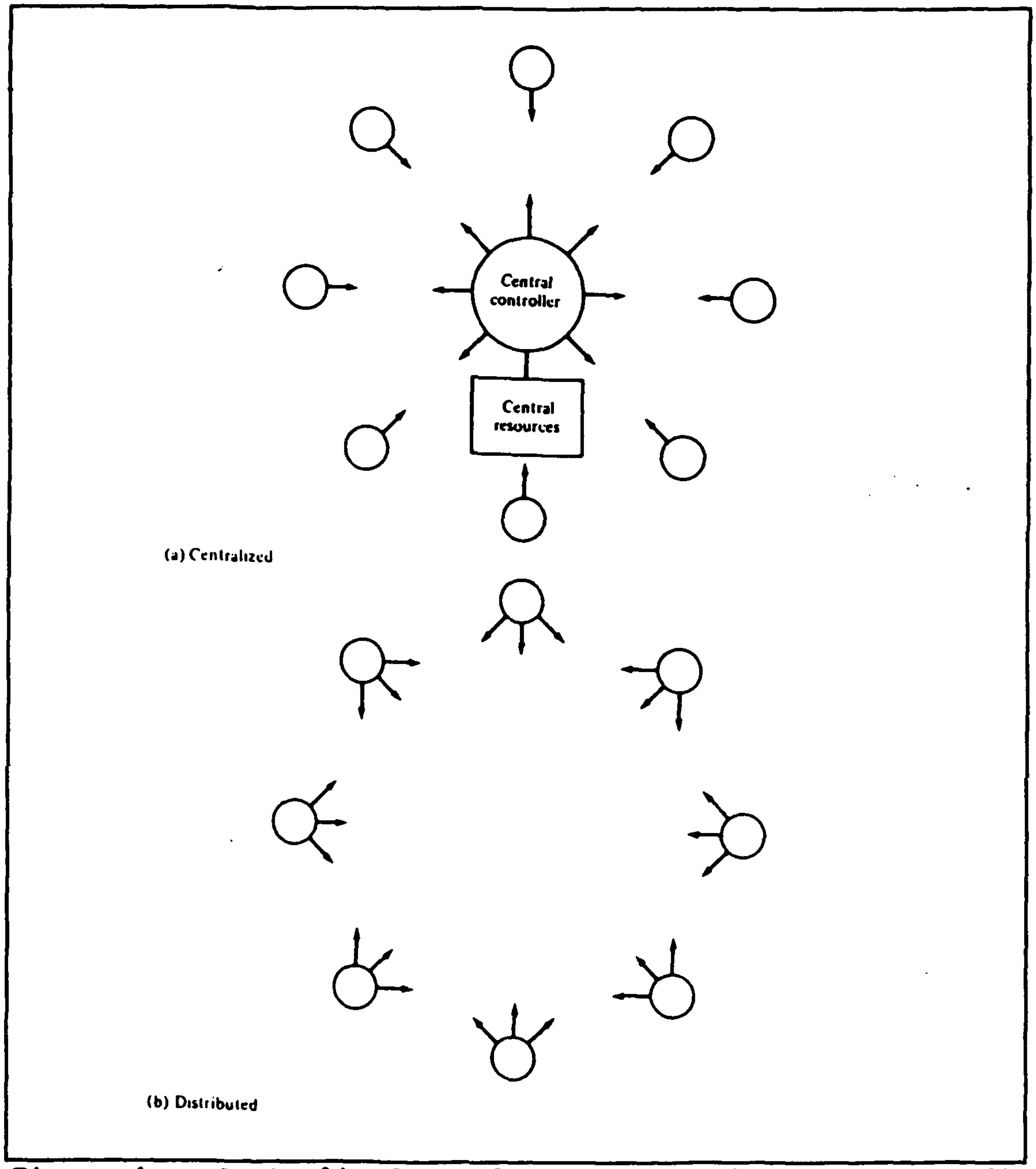

Figure 4. Centralized and Distributed Packet Radio Architectures [Ref. 15:p. 287]

relayed via satellite. The satellite receives and repeats the transmission, returning it to earth stations. Thus, transmitted signals can be received by multiple stations, located beyond ground transmission ranges. Figure 5 on page 27

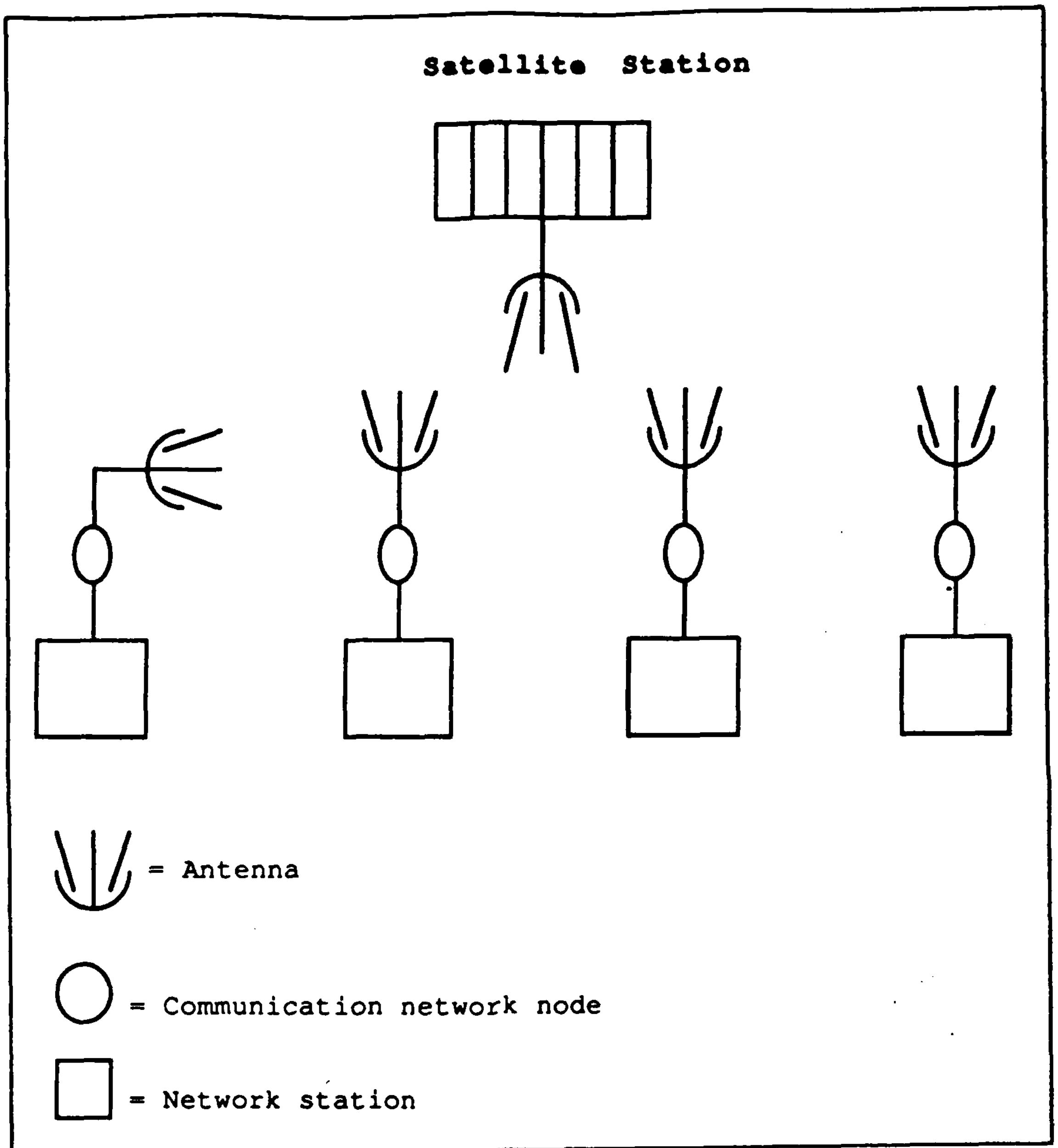

Figure 5. Satellite Network Architecture [Ref. 15:p. 196]

shows an example of satellite network architecture. [Ref. 15:p. 196]

A single satellite provides service to all authorized receivers in its coverage area, which can be a state, nation, or region. Satellite networks can beam their transmissions selectively, enabling one user to communicate specifically with one or more distant users, rather than with all of the thousands or millions of others attached to the network. Such systems permit the sharing of equipment among numerous nonsimultaneous users. [Ref. 16:pp. 85-88]

C. UNDERSEA LIGHT WAVE COMMUNICATION NETWORKS

The vast majority of transoceanic commercial and military communications are transmitted using either satellites in geosynchronous orbits or coaxial undersea cables carrying analog signals. Both technologies are mature and have proven to be reliable. However, single-mode optical fiber technology has resulted in development of digital-signal fiber optic undersea cable network systems. Fiber optic cable (also called lightguide cable) can achieve larger capacity with longer repeater spacings and smaller cable diameters. The result is a highly advanced fiber optic system and a relatively economic undersea cable system. [Ref. 17:pp. 82-91]

Undersea lightguide cable systems offer several advantages over satellite transoceanic communication.

* There are no delays or echo effects on voice and data channels.
* System costs are lower.
* The undersea environment provides immunity from atmospheric disturbances and multipath fading.
* Signals cannot be jammed.

* The systems are secure, since they are extremely difficult to tap without system failure. [Ref. 17:p. 92]

IV. NETWORK COMMUNICATION METHODOLOGIES

To communicate is to transmit ideas, feelings, and information so that they are satisfactorily received and understood. A computer network is a set of computers using common protocols to communicate via some connecting transmission medium. These networks can be used to communicate between individuals and organizations located in a single building or in several cities or countries. Distributed computer networks are designed to take maximum advantage of resource sharing for the transfer of data. The rapid evolution of computer technology has resulted in extensive use of personal computers (PCs) at all levels of computer network systems.

A. LOCAL AREA NETWORKS

Local area networks (LANs) are defined as the interconnection of computers via telecommunications devices in a single building or complex of building to form a network of small geographic scope, using an organization's own telecommunications media [Ref. 4:p. 722]. LANs have grown in popularity with the widespread use of PCs in offices and organizations. LANs may link workstation terminals and other pieces of computer equipment that are only a few yards apart or that span distances of several miles. The nature of a specific LAN is determined primarily by three factors: the transmission medium used, the type of network topology or architecture, and the types of control protocol used for LAN access.

1. Transmission Media for LANs

The transmission medium for a LAN is the physical path between transmitter and receiver in the data transmission system. The characteristics and quality of data transmission are determined both by the nature of the signal and the nature of the medium. [Ref. 15:pp. 47-49]

The principle criterion used to select a LAN transmission medium is cost. This is established as cost per data channel per mile for both high and low capacity systems. Construction costs are important, as well as operation and maintenance costs [Ref. 18:p. 9.1]. Transmission media generally are classed as guided and unguided, depending on whether the signal is channeled through a wire or similar device or whether it is transmitted through the air. Only guided media are used for LANs. The three most important varieties are twisted-pair wires, coaxial cables, and fiber optic cables.

a. Twisted-Pair Wires

Twisted pair systems consist of two insulated copper wires arranged in a regular spiral pattern. The wires in a pair have thickness of from 0.016 to 0.036 inch. One wire pair acts as a single send-and-receive communication link. Over longer distances, cables may contain hundreds of pairs.

The twisting of individual pairs minimizes electromagnetic interference between the pairs. These systems are used to transmit both analog and digital signals. For analog signals, amplifiers are required about every 5 to 6 km. For digital signals, repeaters are used every 2 or 3 km [Ref. 15:pp. 46-47].

b. Coaxial Cable

Coaxial cable, like twisted-pair wires, consists of two conductors, but it is constructed differently to permit it to operate over a wider range of frequencies. This is the most versatile transmission medium and is used in a wide variety of applications. A single coaxial cable has a diameter of from 0.4 to 1 inch. It is an important part of the long distance telephone network, and is becoming extensively used for wide-area networks. [Ref. 15:pp. 50-51]

Coaxial cable can support a large number of communication devices using a variety of data and traffic types. Systems are practical for single buildings or for a complex of buildings. Coaxial cable is used to transmit both analog and digital signals, both of which are used for LANs.

c. Fiber Optic Cables

An optical fiber is a thin, flexible strand capable of conducting an optical ray as a transmission medium. Various types of glass and plastic can be used to make optical fibers.

A fiber optical cable has a cylindrical shape and consists of three concentric sections: the core, the cladding, and the jacket.

These systems transmit a signal-encoded beam of light by means of total internal reflection within each fiber. Only analog signaling is possible in optical fiber, but, with appropriate modulation, either digital or analog data may be carried.

d. Advantages and Disadvantages of the Various Transmission Media

Characteristics of the three kinds are transmission media are summarized in Table II on page 34. Twisted-pair wires are most commonly used in telephone systems and in the workplace for within-building communications. They are limited in communications distance, bandwidth, and data rate. The medium is quite susceptible to interference and noise because of its easy coupling with electromagnetic fields. Twisted-pair wires are the medium of choice for low-cost microcomputer local networks within buildings.

Coaxial cable has superior frequency characteristics, when compared to twisted-pair wires. It can be used effectively at higher frequencies and data rates. It is also much less susceptible to interference and crosstalk than are twisted-pair wires. Coaxial cable is commonly used for short-range connections between devices. An almost explosive growth area for coaxial cable is in local area

TABLE II. COMPARISON OF POINT-TO-POINT TRANSMISSION CHARACTERISTICS OF GUIDED MEDIA

	TWISTED PAIR	COAXIAL CABLE	FIBER OPTIC
WEIGHT	Light	Medium	Light
COMPLEXITY	Low	Medium	High
COST	Low	Medium	High
CAPACITY	Low	Medium	High
BANDWIDTH	250 KHz	350 MHz	2 GHz
TRANSMISSION RATE	10 Mbps	500 Mbps	2 Gbps
DELAY DISTRIBUTION	High	Low	High
REPEATER SPACING	2-3 km	1-6 km	10-100 km

networks. It is the medium of choice for many local network systems.

When compared to twisted-pair wires and coaxial cables, optical fiber can handle greater bandwidth, yet is smaller in size and lighter in weight. Fiber optic cable has lower attenuation rates, better electromagnetic isolation of signals, and permits greater repeater spacing.

Fiber optic enjoys considerable use in long-distance telecommunications and its use in military applications is growing. Continuing improvements in performance and decline in prices has resulted in new areas of application, including wide area video distribution and LANs. [Ref. 15:pp. 46-57]

2. Network Topologies for LANs

The topology of a network describes the arrangement of the interconnections between nodes and stations. A number of nodes can be interconnected in numerous ways to form a network. The most common LAN topologies are called star, ring, bus, and tree. [Ref. 19:p. 11]

a. Star Topology

In the star network configuration, a central switching element is used to connect all the nodes in the network, as shown in Figure 6(a) on page 36. The central element uses circuit switching to establish a dedicated path between two stations wishing to communicate. Twisted-pair wires usually are used to link the stations to the central switch. This simple type of topology is adequate to support the basic transmission needs of a small LAN.

b. Ring Topology

Ring computer network topology consists of a closed loop, with each node attached to a repeating element, as illustrated in Figure 6(b). Data circulate around the ring on a series of point-to-point data links between repeaters. A station wishing to transmit waits for its next turn and then sends data out onto the ring in the form of a packet. The packet contains source and destination address fields as well as data. As the packet circulates, the destination station copies the data into a local buffer. The packet continues to circulate until it returns to the source station, providing a form of acknowledgment. A distributed control protocol is used to determine the sequence in which nodes transmit.

Because the ring is constructed as a series of point-to-point links, almost any electrical or data

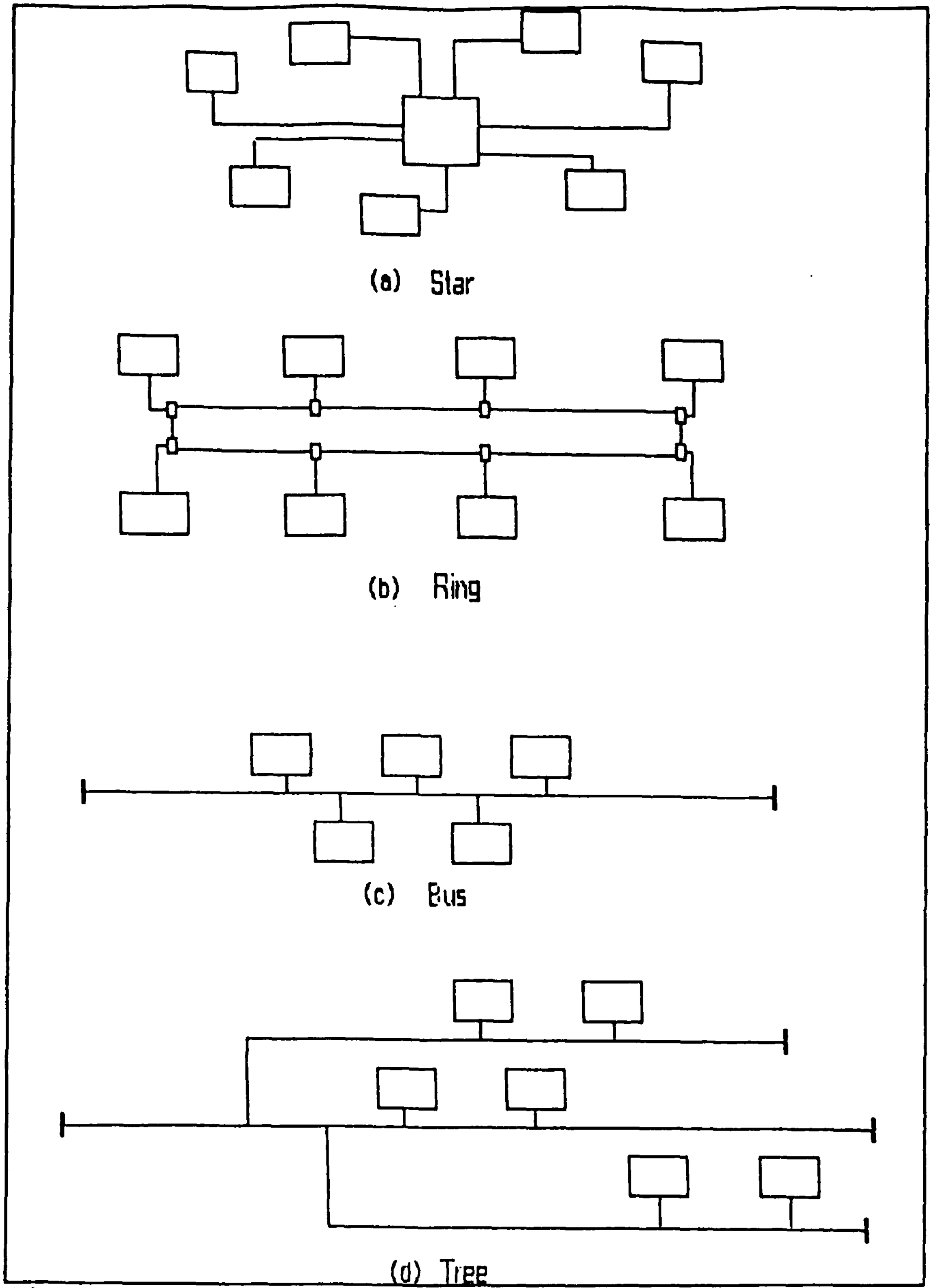

Figure 6. Four Possible LAN Topologies

transmission medium can be used. Twisted-pair wires is the most common, providing transmissions at rates up to 10 Mbps. Coaxial cable can be used to achieve higher data rates. Optical fiber is used to achieve very high data transfer rates. [Ref. 15:p. 332]

c. Bus and Tree Topology

Both bus and tree LAN topologies are characterized by the use of a single transmission medium to which stations are attached at several points. Bus topology is a special case of the tree configuration in which there is only one trunk, with no branches (Figure 6(c) and 6(d)). Because all devices share a common communications medium, only one pair of devices on a bus or tree can communicate at a time. Transmissions consist of packets, each of which contains a source and destination address field to indicate the sending and receiving stations. Each station continuously monitors the transmission medium and copies packets addressed to itself.

Twisted-pair wiring is the most common communications transmission medium used for bus and tree LANs. Although, transmission speeds are low, wire is the most cost-effective choice for a single building with low traffic requirements. When higher performance is required, coaxial cables should be used. These can span greater distances than twisted-pair wires.

LANs utilizing bus or tree topologies can use two transmission methods: baseband and broadband. Baseband systems use the entire bandwidth of the transmission medium to carry the signal. These systems are simple to install and maintain. They typically transmit at rate from 1 to 10 Mbps and are generally limited to a single building. However, by limiting the distance covered and the number of devices attached, data rates of 50 Mbps can be achieved. Broadband systems also typically transmit in the range of 1 to 10 Mbps for a single data path, with 20 Mbps representing a practical upper limit. However, broadband systems can support multiple data paths in contrast to the single data path of baseband. Hence interbuilding and even city-wide networks can be supported. [Ref. 15:p. 333]

Optical fiber has greater transmission capacity than coaxial cable. However it has been little used so far for bus and tree topologies due to cost and technical limitations. Future network installations probably will use this medium, as costs drop. [Ref. 15:p. 333]

d. Advantages and Disadvantages of the Various Topologies

A major advantage of a star LAN is that it may be made resilient to cable breaks by allowing the central relay to ignore broken cables. However, it is less reliable than a bus or tree. More cable is required than a bus or ring needs for a similar size system.

Ring topology is best suited for environments with a small number of nodes which operate at high speeds over short distances. A disadvantage is that a break in the ring will cause the network to stop functioning; thus it is vulnerable to sudden and fatal failure.

Bus and tree topologies provide high reliability, and require fewer cables than does a star. Also, these systems have the capability to permit connection of a wide range of devices to the network, including broadcast devices. As a disadvantage, they are vulnerable to physical damage; a single break may partition them into two or more parts, none of which can function properly [Ref. 20:pp. 56-58]. Bus and tree topologies provide the most options and greatest feasibility of the various LAN topologies and thus currently dominate the marketplace.

3. Media Access Control of LANs

Only one station can transmit data at a time in a LAN, because all stations share a common transmission medium. Therefore some medium access control (MAC) scheme is necessary to determine which station may transmit next, without data collision. Three MAC protocols are commonly used. These techniques are called carrier sense multiple access with collision detection (CSMA/CD), token bus, and token ring.

a. Carrier Sense Multiple Access With Collision Detection (CSMA/CD)

CSMA/CD is the most commonly used transmission medium access control technique for bus and tree topologies, which are the most widely used LAN topologies. Systems using this protocol are referred to as "listen while talk" LANs. That is, a station wishing to transmit "listens" to the transmission medium and, if it is busy, waits until the medium becomes idle. The station then transmits when it senses that the medium is idle. While transmitting, it continues to listen for signals directed to itself. If the station detects some form of data collision, it absorbs the transmission immediately. After a random backoff time, it then retransmits the data. Figure 7 on page 41 illustrates how the system works.

b. Token Bus Access Control

Token bus control of access to a transmission medium is used for bus and tree topologies. It is a technique in which the stations on the bus or tree form a logical ring. That is, the stations are assigned positions in an ordered sequence. Each station knows the identity of the stations preceding and following it [Ref. 15:p. 351]. A control packet known as the token regulates the right of access. When a station receives the token, it is granted control of the medium for a specified time. The station may transmit one or more packets and may poll stations and receive responses. When the station is done transmitting or time has expired, it passes the token to the next station in the sequence. This next station now has permission to transmit.

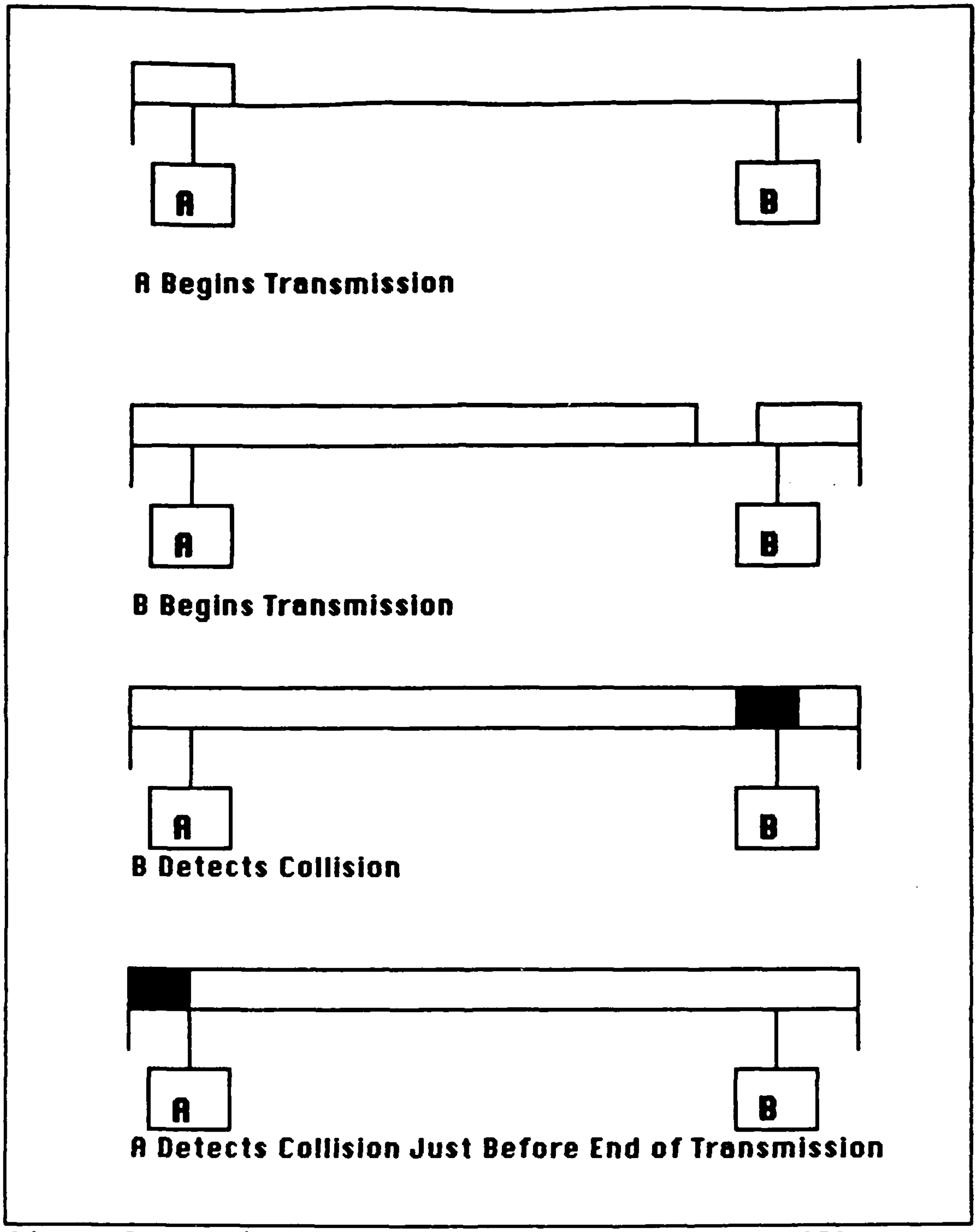

Figure 7. CSMA/CD LAN Access Control [Ref. 15:p. 350]

c. Token Ring Access Control

The token ring network access control technique is used only with ring architectures. It is based on the use of a small "token" data packet that circulates around the ring. When all stations are idle, the token packet is labeled as a "free token." A station wishing to transmit must wait until it detects the free token passing by. It then changes the token from "free token" status to "busy token" status by altering the bit pattern. The station then transmits a data packet immediately following this busy token.

Other stations wishing to transmit data must wait until the busy token and packet make a round trip and are purged by the transmitting station. The transmitting station then inserts a new free token on the ring when the transmission is complete. Figure 8 on page 43 illustrates how this system works.

d. Advantages and Disadvantages of the Various Access Control Protocols

Table III on page 44 compares the three kinds of access control protocols. CSMA/CD protocols have no upper bound on possible delay for station access to the transmission medium. Performance generally is poor under heavy traffic, but adequate with light traffic.

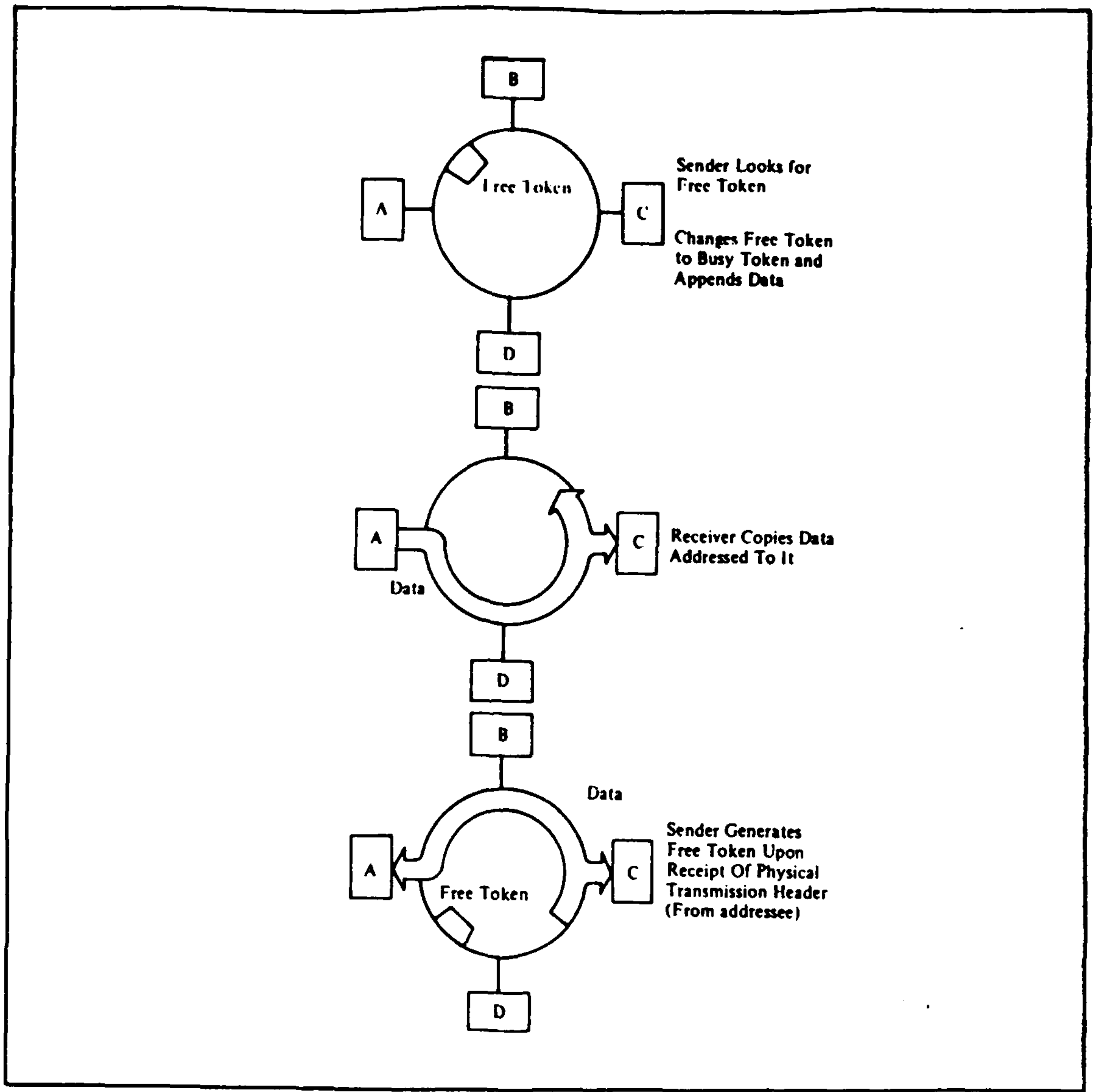

Figure 8. Token Ring LAN Access Control [Ref. 15:p. 356]

Token bus access systems have a deterministic upper bound on medium access delay. Under heavy traffic, delays generally are shorter than with CSMA/CD protocol, but longer under light traffic.

Token rings, like token buses, have a deterministic upper bound on the medium access delay. Similarly, under heavy

TABLE III. COMPARISON OF CSMA/CD, TOKEN BUS, AND TOKEN RING ACCESS METHODS

	CSMA/CD	TOKEN BUS	TOKEN RING
ACCESS DETERMINATION	Contention	Token	Token
PACKET LENGTH	Greater than 2 x propagation delay	None	None
PRINCIPLE ADVANTAGE	Simplicity	Regulated fair access	Regulated fair access
PRINCIPLE DISADVANTAGE	Performance under heavy load	Complexity	Complexity

traffic, delays are shorter than with CSMA/CD system, but longer under light traffic.

B. WIDE AREA NETWORKS

Wide area networks are communication networks used for long-haul transmissions. They have two distinguishing characteristics. First, they span broad geographical distances, ranging from a few miles to thousands of miles. Second, they use common carrier networks, such as the telephone network. [Ref. 21:p. 422]

Wide area networks generally use unguided transmission media. That is, signals travel through the air rather than through wires or cables. With such systems, the spectrum or frequency band of the signal produced by the transmitting antenna is more important than is the transmission medium, in determining transmission characteristics. At lower frequencies, signals are omnidirectional, that is, the signals propagate in all directions from the antenna. At higher frequencies, it is possible to focus the signals into a directional beam. [Ref. 21:p. 423]

Several signal transmission techniques are used for wide area networks. The three most common make use of terrestrial microwave stations, satellite microwave stations, and radio transmissions.

1. Terrestrial Microwave Stations

The primary use for terrestrial microwave signal transmission is for wide area telecommunications service. Like coaxial cable, microwave signals can support high data rates over long distances. The microwave facility requires far fewer amplifiers or repeaters than coaxial cable for the same distance, but requires line-of-sight transmissions. Microwave signals also are used for short point-to-point links between buildings, as with local area networks. Terrestrial microwave stations are used for providing digital data transmission for small regions, that is, for areas with a radius of less than 10 km.

The higher the frequency used, the higher the potential data rate. With the growing popularity of microwave systems, transmission areas sometimes overlap and interference is always a danger. Thus, the assignment of frequency bands is strictly regulated by Federal Communications Commission (FCC) in the United States. [Ref. 15:p. 57]

2. Satellite Microwave Stations

A communication satellite is, in effect, a microwave relay station. It is used to link two or more ground-based microwave transmitter-receivers, known as earth stations or ground stations. The satellite station receives transmissions on a given frequency band, amplifies (analog transmission) or repeats (digital transmission) the signal, and transmits it on another frequency. Communications satellites are being used today to handle telephone, telex, and television traffic over long distances. Satellite transmissions provide the optimum medium for high-usage international trunks and are competitive with terrestrial microwave and coaxial cable for many long-distance international links.

3. Radio Communication Systems

A basic radio communications system consists of a transmitter, an antenna system, and a receiver. The transmitter generates a radio frequency signal and modulates it as appropriate for the information being transmitted. Essentially, modulation is the process of varying the parameters of a signal in some way to maximize information transfer. Transmission lines carry this modulated signal from the transmitter to the transmitting antenna which radiates energy into space in the form of radio waves. The radio waves then propagate through space and are received by a receiving antenna. Transmission lines carry this signal to the receiver which converts it into a form from which the information can be extracted.

Successful communication by means of radio waves depends on the power of the transmitter, the frequency used, the distance between the transmitter and receiver, and the sensitivity of the receiver. The ability of the earth's atmosphere to conduct energy to its destination, together with the nature of the terrain between the sending and receiving points, will determine the frequency used to transmit the radio signal.

4. Advantages and Disadvantages of the Various Signal Transmission Techniques

Figure 9 on page 48 illustrates the relationship of radio and microwave frequencies to the total electromagnetic spectrum. Radio is a general term sometimes used to encompass signals and transmissions using all the frequency bands from 100 KHz to 30 GHz [Ref. 15:pp. 56-61]. However, for this study that total spectral area is separated into two categories: microwave (1 GHz to 30 GHz) and radio (30 KHz to 1 GHz).

Electromagnetic waves used for communication are divided into three kinds.

* Surface waves: the part of the ground wave that is affected by the conductivity of the earth. Frequencies used are between 30 KHz and 3 MHz.

* Sky waves: the portion of the radio wave which moves upward and outward and is not in contact with the earth, but is propagated by the ionosphere. Frequencies used are between 1 MHz and 30 MHz.

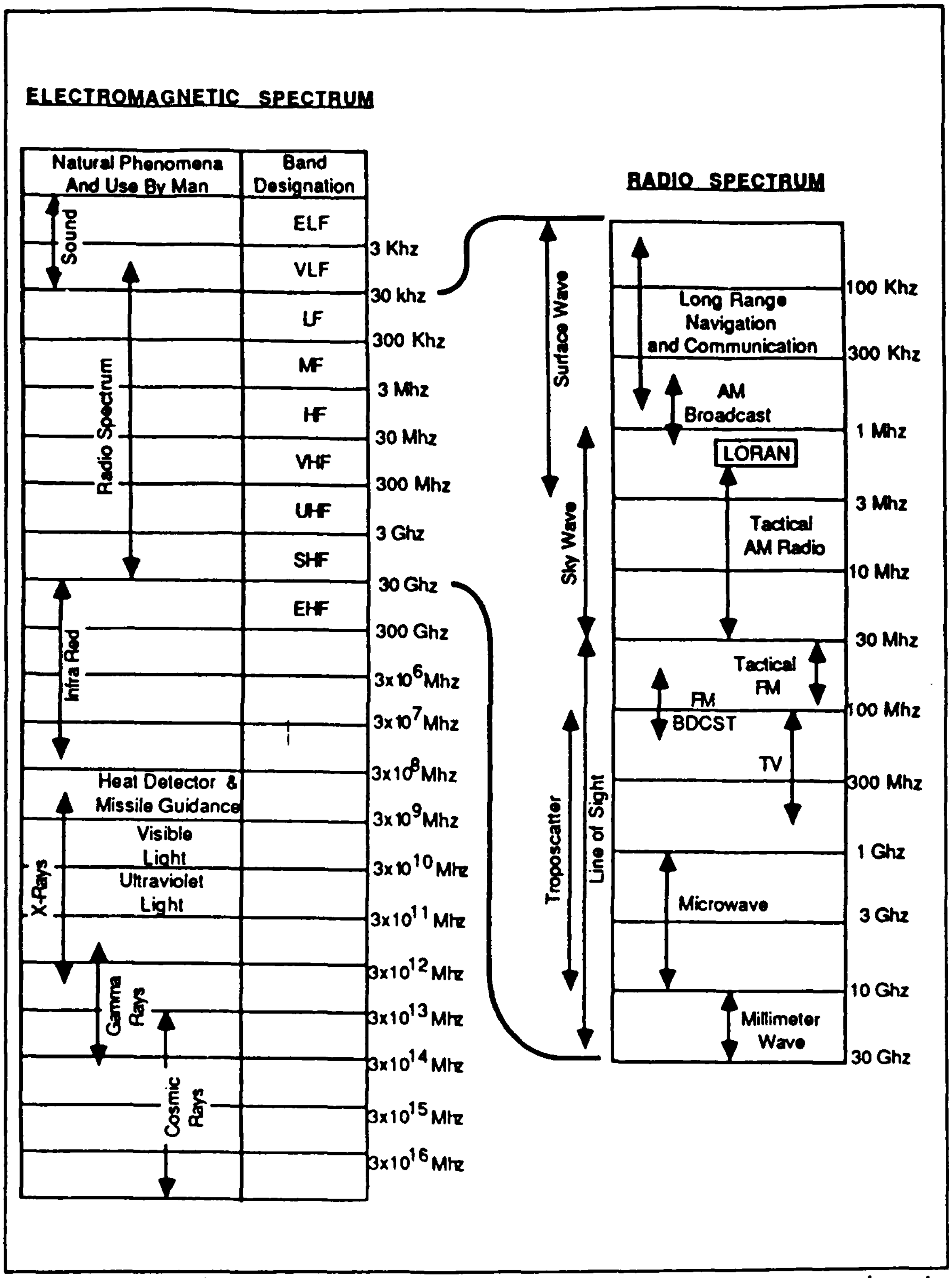

Figure 9. Relationships of Radio and Microwave Frequencies to the Total Electromagnetic Spectrum

* Troposphere waves: waves moving through the lower part of the earth's atmosphere, lying between the surface of the earth and the stratosphere. This area is characterized by rapid changes in humidity, atmospheric pressure, and temperature. Frequencies used are between 100 MHz and 10 GHz.

Common frequencies used for terrestrial microwave transmissions are in the range of 1 to 30 GHz. The higher microwave frequencies (that is, millimeter wave frequencies) are less useful for longer distances because of increased attenuation, but are quite adequate for shorter distances. In addition, at the higher frequencies, antenna are smaller and cheaper.

The optimum frequency range for satellite transmission is in the range of 1 to 10 GHz. If two satellites are close enough together and are using the same frequencies, they will interfere with each other. Because of the long distances involved, there is a propagation delay of about 240 to 300 ms from the time of transmission from one earth station to reception by another earth station via satellite.

Satellite microwave is inherently a broadcast medium. Many stations can transmit to the satellite, and a transmission from a satellite can be received by many stations. Satellite transmissions provide the optimum medium for high-usage international communication trunks. Satellite stations are competitive with terrestrial microwave stations and coaxial cable for many long distance international links.

The principle difference between radio and microwave signals is that radio signal transmissions are omnidirectional while microwave transmission are focused. Radio stations do not require dish-shaped antennas, and the antennas need not be rigidly mounted to a precise alignment.

The range from 30 MHz to 1 GHz is especially effective for radio broadcast communications. Unlike the higher frequencies of the microwave region, radio waves are less sensitive to attenuation from rainfall. However, a prime source of impairment for radio waves is multipath interference. Reflections from land, water, and natural or human-made objects can create multiple paths between antennas. [Ref. 15:pp. 36-41]

V. UNIFIED NETWORK SYSTEMS FOR ROC C3 FUNCTIONS

Existing shore-based and ship-based C3 systems consist of discrete, diverse, unintegrated subsystems, which cannot operate alone and are not all compatible with each other.

Computer networks will improve communication connectivity, reliability, performance, and fault analysis capability, as needed to support today's C3 requirements. Various kinds of C3 equipment and subsystems may be used by more than one shore or ship facility, if connected via a computer network. This will result in more efficient and effective use of resources. However, it is critical that a standard set of protocols be selected for the ROC Navy network, if interoperability of equipment is to be achieved. Information provided in Chapters III and IV of this thesis will assist in determination of the best set of standards.

A. SHORE-BASED COMMUNICATIONS NETWORKS

Shore-based communications networks will consist of both local area networks for individual bases and wide-area networks for inter-base communications. A combination of telephones and computer networks can provide efficient and responsive service for both intra- and inter-base communications.

1. Wide Area Networks

The ROC Navy has three large shore bases as shown in Figure 10 on page 53. A comprehensive, well-planned communications architecture is necessary to integrate the existing independent communications systems of these ROC Navy bases through a backbone transmission and switching system. Such a system then can provide voice, data, image, and video communications services that are compatible and effective at all sites [Ref. 22:p. 12].

As noted in Chapter III, these interbase networks can be either switched or broadcast communication networks. If a switched network is used, either circuit, message, or packet switching techniques can be used, although most modern systems use packet switching. Signals could be transmitted via radios, but most likely microwave systems will be used for these relatively long-haul communications, as discussed in Chapter IV.

One solution would be to model the ROC Navy's interbase network on the U.S. Defense Data Network (DDN) [Ref. 23:p. 5]. The DDN is a packet-switched network (see Chapter III). This well-established system offers many technical enhancements that could be used to meet the increasing needs of ROC Navy for information processing and transfer.

2. Local Area Networks

On a single base, U.S. Navy data communications currently are provided via the switched telephone system when

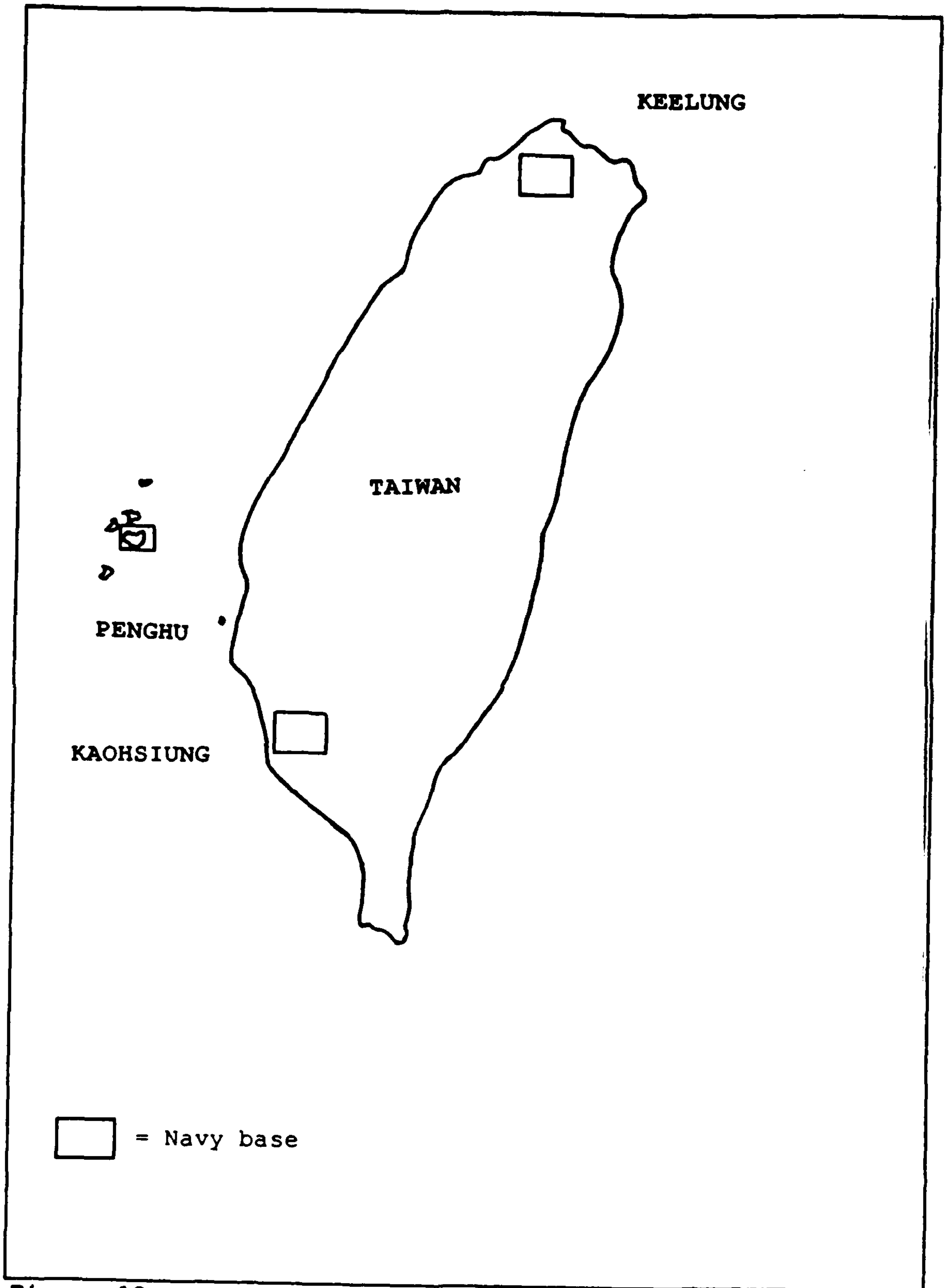

Figure 10. Navy Bases in Taiwan

low data rates and small volumes of traffic are involved and suitable modems are available. Dedicated phone lines and LANs are used when data rates and large volumes of traffic are involved [Ref. 22:p. 2-1]. A similar system could be adopted by the ROC Navy.

For communication on a single base, the flexibility of LANs for dynamic system expansion and reconfiguration is particularly applicable to tactical C3 applications. When command posts must be relocated in a manner that facilitates continued operations, a well-designed LAN will permit graceful decomposition and reestablishment of needed functions as they move from one location to another. [Ref. 24:p. 181]

A well-designed LAN can provide communication means for all kinds of data required for military functions. Chapter IV has included data needed to select a computer networks topology and communication protocols. However, the actual system developed at each base depends on its facilities, data traffic, and physical area.

B. SHIP-BASED COMMUNICATION NETWORKS

The ROC Navy currently has no warships. However, when such ships are designed it is important to utilize technologies that have proven useful in other countries.

LANs are commonly used on some large ships in the U.S. Navy. An integrated computer system on a large warship designed as a LAN is capable of interconnecting various kinds of shipboard computer and communication equipment [Ref. 25:p. 182]. A LAN can facilitate faster data flow between various combat systems on ships by providing the medium for an efficient integrated environment.

C. INTEGRATION OF SHORE BASE AND SHIP NETWORK SYSTEMS

A communication network that links shore bases and ships must include ships at sea and ships in port. Technologies of linkage will vary, depending on a ship's current location.

1. Ships in Port

Ships in port can utilize the same types of communications and communications channels as shore bases. That is, they can use telephones or a DDN-like wide-area network.

2. Ships at Sea

Currently, the method of passing data between shore and ships at sea is via written reports, high frequency radio, Morse code, or various kinds of telecommunication. Computers are already available aboard ships and may be used for future network systems. Ship-to-shore computer networks can be established using satellite microwave technology, as discussed in Chapter IV. Then these networks may be used for real-time data transfer and decision making involving both bases and ships.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The ROC Navy must consider many things before it develops a computer network to apply to C3 functions. A well-designed computer network used for C3 functions will be fast, reliable, and secure. AI techniques will affect future computer systems and must be considered in any new system design. Also, human factors considerations are important in developing and operating a satisfactory computer network as described in Chapter II.

Chapter III has explored the three basic kinds of network techniques used for communication. For ROC intra-base communications, a LAN is particularly adaptable in a small geographical area. For inter-base communications, a network similar to the U.S. DDN could be used effectively. Communication technologies applicable to both LANs and WANs are described in Chapter IV.

A unified network system for C3 functions must link shore-based and ship-based systems. The integration of such varied systems is critical. Chapter V has discussed how a unified system can make C3 functions more efficient for the ROC Navy.

B. RECOMMENDATIONS

This study examined alternatives and provided various requirements related to establishment of LAN and WAN computer networks that may be utilized for C3 functions by the ROC Navy. Command, control, and communications systems and concepts are important at all levels within the structure of the ROC Navy. It is necessary for the ROC Navy to develop or acquire more effective systems for data collecting, analysis, and processing, and for decision making, to improve C3 functions. It is recommended that computer networks be considered as an efficient way to meet these wartime and peacetime needs.

APPENDIX: GLOSSARY

AI	Artificial Intelligence
AM	Amplitude Modulation
BDCST	Broadcast
C3	Command, Control, and Communication
CSMA/CD	Carrier Sense Multiple Access with Collision Detection
DDN	Defense Data Network
EHF	Extra High Frequency
ELF	Extremely Low Frequency
FFC	Federal Communications Commission
FM	Frequency Modulation
HF	High Frequency
LAN	Local Area Network
LF	Low Frequency
MF	Medium Frequency
PC	Personal Computer
PM	Phase Modulation
ROC	Republic of China
SHF	Super High Frequency
UHF	Ultra High Frequency
VHF	Very Low Frequency
WAN	Wide Area Network

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9.	Chen, Chia-Hsin No.10-3, Lane 94 Chung-Shiaw 1 Road Kaohsiung, Taiwan, R.O.C. Navy	6